TECHNICAL REPORT ARBRL-TR-02370

EFFECTIVENESS TESTING FOR ANTIPROPAGATION SHIELDS DEVELOPED FOR M456 HEAT TANK AMMUNITION

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September 1981

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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antipropagation

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)* (eal)

Numerous previous tests demonstrated the effectiveness of polyethylene bars emplaced betweeen rounds of M456 HEAT tank ammunition to prevent a second round detonation given the detonation of a first round. However, these tests had a considerable margin of safety and the reliability and associated confidence level were unknown. In this report, a description is given of the statistical design and tests which were performed to establish the shielding thickness needed to be 90% confident that the probability of a second round detonating, given a first round detonation, was less than 0.1.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

In previous work, conducted for the M1 Tank Project Office (then the XM1), it was demonstrated that detonation of nearest neighbor rounds as a result of detonation of a donor round could be prevented for M456 HEAT warheads by use of polyethylene bars emplaced between each round[1]. While numerous tests demonstrated the effectiveness of the plastic bars, and the thicknesses used contained a considerable margin of safety, the reliability and associated confidence level were unknown. In this effort, we describe a statistical design and tests which were performed to establish the shielding thickness needed to be 90% confident that the probability of a second round detonating, given the detonation of a first round, was less than 0.1.

II. TEST CRITERIA AND EXPERIMENTAL TECHNIQUE

The criterion for successful shielding was that the acceptor rounds not detonate. Thus, reactions of severity less than that of a design-mode detonation, although not necessarily desirable, were considered acceptable. The basis for this choice was the fact that reactions less severe than detonations will not cause further rounds to detonate, and the process of propagation from round-to-round ceases[2].

A typical test set up is shown in Figure 1. The donor round was deliberately detonated using a small charge of C-4 explosive, an RDX booster, and P-3 detonating cord as the initiator. The method of initiation is shown schematically in Figure 2. Shielding thicknesses were varied from test to test, according to the design methodology. Shields were fabricated from sheets of polyethylene of various thicknesses, e.g., a 2.54 cm thick shield was fabricated from two 1.27 cm thick slats, and a 1.59 cm thick shield was fabricated from a 1.27 cm thick slat in contact with a 0.32 cm thick slat. Especial care was taken to insure that the donor and acceptor rounds were in contact with the shielding material. Thus, when shielding thickness was varied, spacing between rounds was varied correspondingly. (This represents a more severe testing case than if the spacing were kept constant.) Tests which involved more than two acceptors had 1.27 cm mild steel plates emplaced between them to prevent cross talk between acceptors in the event that one detonated (see the data sheet for test KAA0331A1, in the Appendix, for a schematic).

Photographs were taken of each test before and after deliberate detonation of the donor round. The response of the acceptor rounds was evaluated by examination of the acceptor fragments (when found) and by examination of the witness plates. Both fragment size and witness plates provided unambiguous assessments of munition response. Thus, when acceptors reacted mildly, or not at all, the acceptors were squashed, cracked open, or broken into several very large pieces. The witness plate behind the acceptor (viewed from the donor)

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[1] *Howe, P., "The Phenomenology of Interround Communication and Techniques for Prevention," ARBRL-TR-02048 (1978) (AD #A054373).*

[2] *This fact has not, as yet, been documented anywhere. It is the conclusion of one of the authors (P. Howe) based on several years of effort in studying propagation mechanisms.*

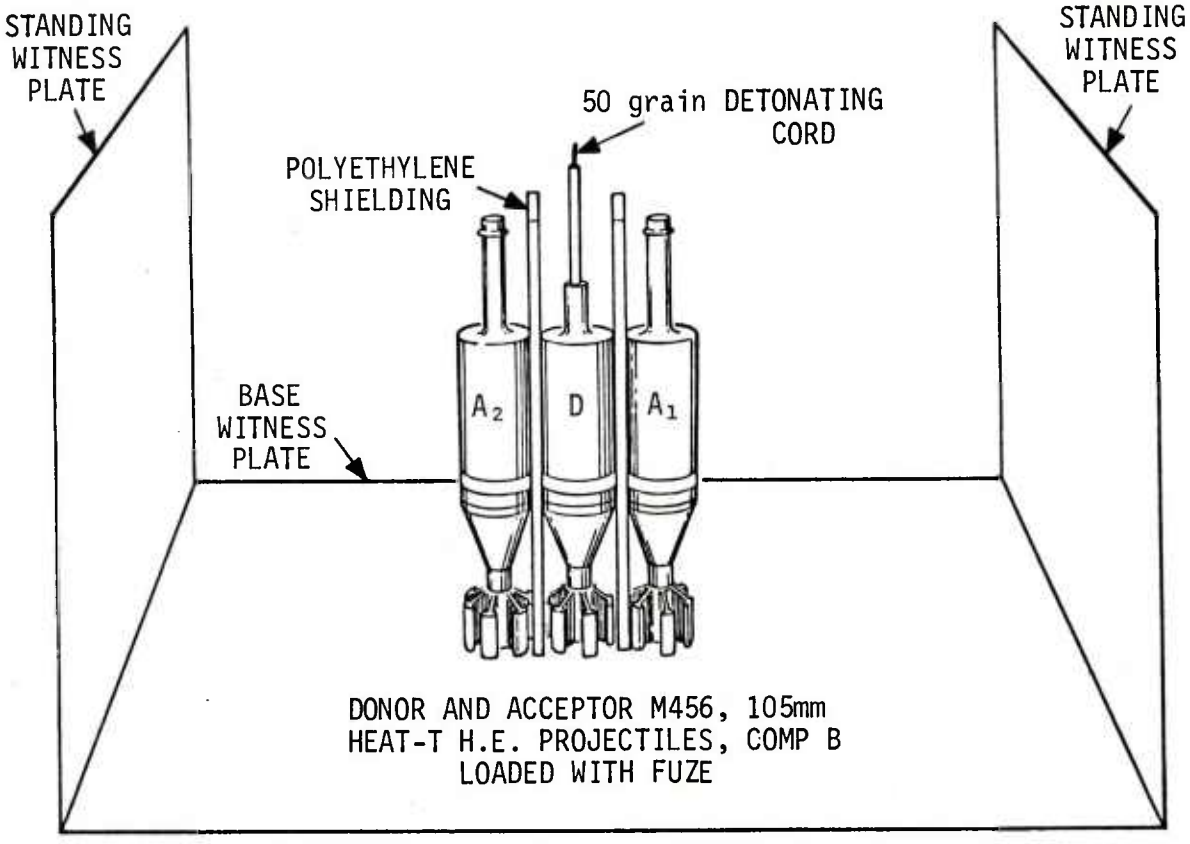


Figure 1 - Typical Test Setup

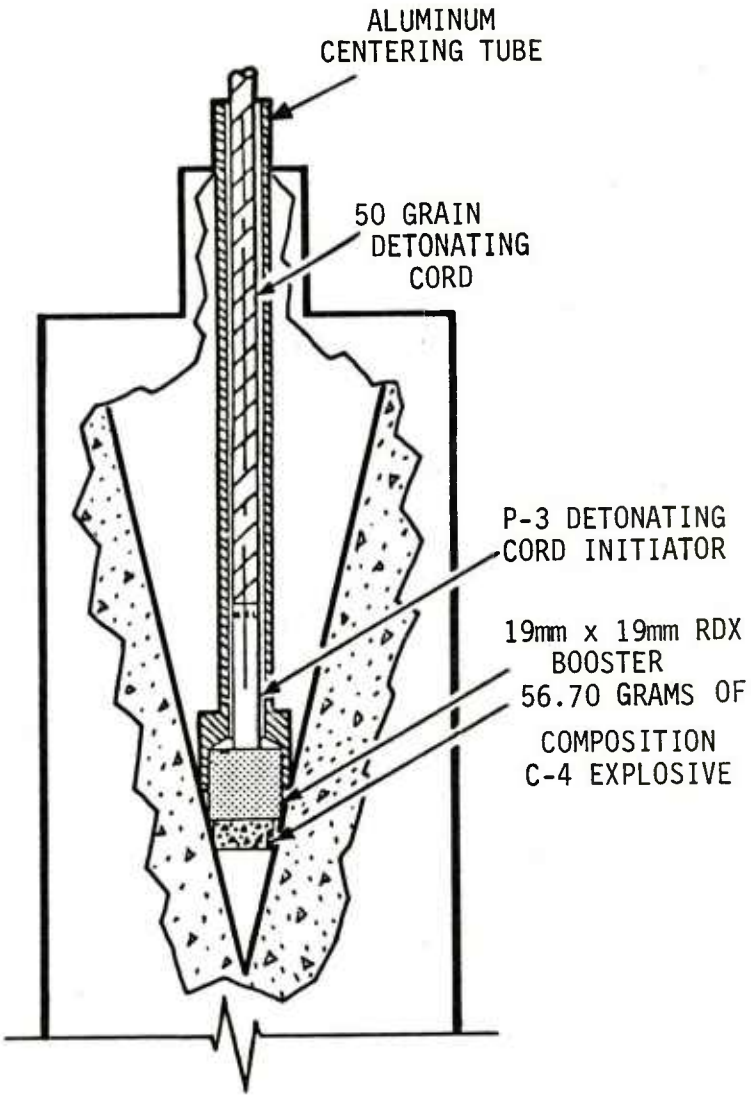


Figure 2 - Method of Detonation of Donor M456, 105 mm HEAT-T H.E. Projectile, Comp B Loaded with Fuze

was frequently coated with explosive. In the regions of the witness plates shadowed from the donor by the acceptors, there were no fragment perforations. This was true both for side witness plates and base witness plates. Compare, for example, the damage to the witness plates in test No. KAA0330E1, where the acceptor round detonated (Appendix, p. 21) and test No. KAA0331A1, where none of the three acceptors detonated (Appendix, p. 23).

III. STATISTICAL DESIGN

The purpose of the test, as previously stated, was "to establish the shielding thickness needed to be 90% confident that the probability of a second round detonating, given the detonation of a first round, was less than 0.1." Since the probability of interest was $\alpha = 0.1$, and is therefore in the tail of some unknown response distribution, the problem appeared to fit into the category of extreme value quantal response designs. Quantal response means that the result has only two possible choices, in this case detonation or nondetonation. Also, because of the lack of information about the response function, a nonparametric test design was used, Modified Alexander Extreme Value (MAEV) Design.

The MAEV design rules are given below. (For more detail, see reference 3.)

1. The first test level is X_r, the best a priori guess of X_α. X_α is the shielding thickness where the probability of a response (detonation) is $\alpha = 0.1$. $\delta = 3.18$ mm is the step size between levels.

2. One acceptor per donor is used, in a decreasing shielding thickness sequence, until a response is observed. Let X_d be the highest level at which a response is observed.

3. After the first response, the number of acceptors per donor in each test is increased to alternately three and then four. After the first response, three acceptors per donor are tested at the next three levels above X_d. Then four acceptors per donor having shielding at levels X_d and the next three higher levels are tested.

4. If another response is observed at a higher level, it becomes X_d, and testing continues alternating three and then four acceptors per donor until at least 12 (more than half the required 22) nonresponses have been observed at the two levels immediately above X_d.

5. When at least 12 nonresponses have occurred at $x_d + \delta$ and $x_d + 2\delta$, the number of acceptors per donor is reduced to alternately two above X_d and then three, starting at X_d, for the remainder of the test.

6. Testing terminates when at least N (22) nonresponses have been observed at the two levels immediately above the highest level at which a response has been observed.

[3] *Smith, J. H. and Thomas, J., "Extreme Value Quantal Response Experimental Design," ARBRL-TR-02325 (1981).* (AD #A101188)

The 22 nonresponses were arrived at in the following manner. If the probability of a response at X_α is equal to α, then the probability of not getting a response is $1 - \alpha$. Assuming the tests are independent, the probability of n nonresponses in n tests is $(1 - \alpha)^n$. Then, $1 - (1 - \alpha)^n = P$, is the probability of at least one response in n tests. In our case, $P = 0.9$ and $\alpha = 0.1$. Solving for n and letting $N = [n] + 1$, we get $N = 22$. Thus, after observing 22 nonresponses at $X_d + \delta$ and $X_d + 2\delta$, we can conclude that the level at which the true probability of response is 0.1 is less than $X_d + 2\delta$ with ninety percent confidence.

IV. RESULTS

A summary of the test results is given in Figure 3. The first test, KAA0330A1, had a shielding of 22.23 mm thick between the acceptor and the donor round. The acceptor did not detonate. The shielding thickness was decreased to 15.88 mm for the second test and to 12.70 mm for the third test with no detonation in either test. The acceptor round detonated on the fourth test with a shielding thickness of 9.53 mm between the acceptor and donor.

In all, 14 tests were conducted using 34 acceptors and 14 donors. No acceptor rounds detonated with shielding thickness greater than 9.53 mm between the acceptor and donor round. Of the six rounds tested with shielding thickness of 9.53 mm, four detonated and two did not detonate.

V. CONCLUSIONS

1. It was demonstrated that polyethylene bars between M456 HEAT rounds would prevent detonation of the second round if the bar was thick enough.

2. It was estimated that the probability of a second round detonating, given the detonation of a first round, to be less than 0.1 with 90% confidence if the shielding thickness is 15.88 mm or more.

	POLYETHYLENE SHIELDING THICKNESS (mm)						
	3.18	6.35	9.53	12.70	15.88	19.05	22.23
ROUND NO.							
KAA0330A1							0
KAA0330B1					0		
KAA0330D1				0			
KAA0330E1			X				
KAA0331A1				0	0	0	
KAA0331B1			X	0	0	0	
KAA0331C1				0	0	0	
KAA0331D1			X	0	0	0	
KAA0331E1				0	0	0	
KAA0331F1			0	0	0		
KAA0331G1				0	0		
KAA0331H1			0	0	0		
KAA0331I1				0	0		
KAA0331J1			X	0	0		

X: DETONATION
O: NON-DETONATION

Figure 3 - Summary of Test Results

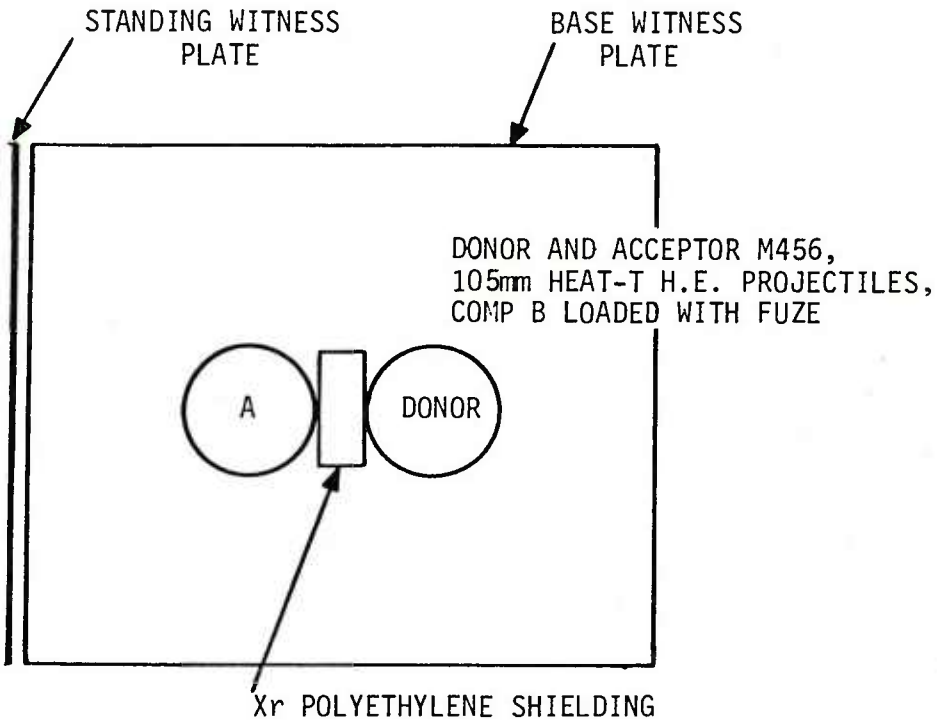
APPENDIX

COMPARTMENTALIZATION SHIELDING TEST

DATA SHEETS AND DAMAGE PHOTOS — Page

COMPARTMENTALIZATION SHIELDING TEST

TEST NO: KAA0330A1 DATE: 30 MARCH 1981 TIME: 1145 MST



Xr = 22.23mm

(Witness plates are 2.67mm thick mild steel)

RESULTS: Acceptor round did not detonate and was recovered almost intact. The projectile was blown open above the rotating band. The standing witness panel had one large perforation, and unburned explosives were deposited on it. The base witness plate had a tailfin imprint from the detonation of the donor round.

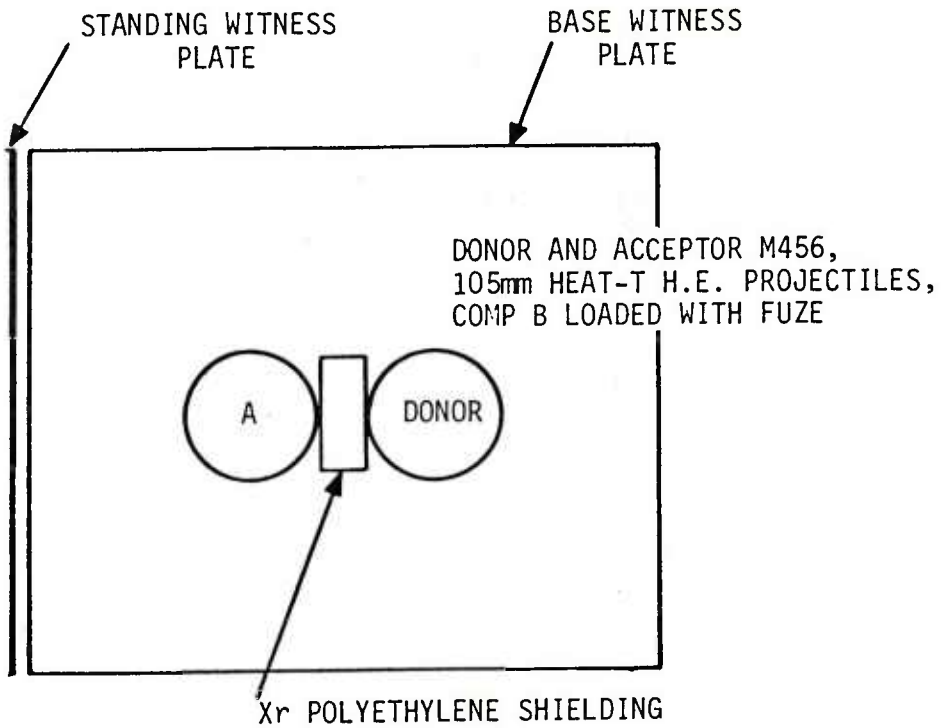
TEST NO: KAA0330A1
DATE: 30 MARCH 1981

DONOR AND ACCEPTOR
PROJECTILES BEFORE TEST

ACCEPTOR PROJECTILE
RECOVERED AFTER
TEST

COMPARTMENTALIZATION SHIELDING TEST

TEST NO: KAA0330B1 DATE: 30 MARCH 1981 TIME: 1145 MST



Xr = 15.88mm

(Witness plates are 2.67mm thick mild steel)

RESULTS: Acceptor round did not detonate. A large side fragment and large segment of the boom from the acceptor round were recovered. Several large perforations and unburned and burned explosive were apparent on the standing witness panel. The base witness plate had a tailfin imprint from the detonation of the donor round.

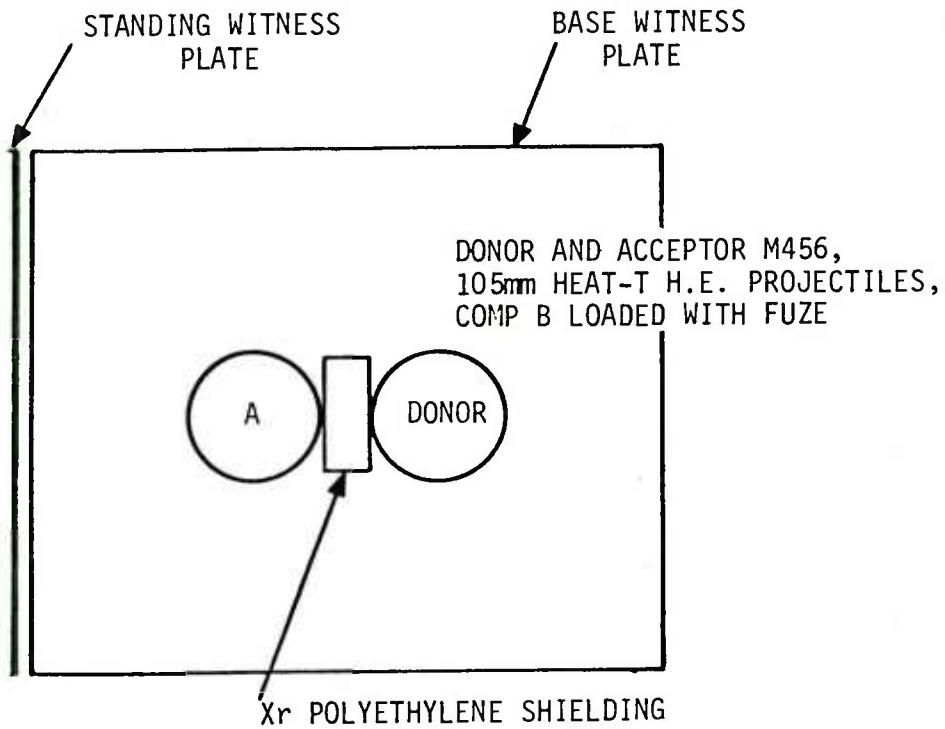
TEST NO: KAA0330B1
DATE: 30 MARCH 1981

DONOR AND ACCEPTOR
PROJECTILES BEFORE TEST

FRAGMENTS OF ACCEPTOR PROJECTILE
RECOVERED AFTER TEST

COMPARTMENTALIZATION SHIELDING TEST

TEST NO: KAA0330D1 DATE: 30 MARCH 1981 TIME: 1530 MST



Xr = 12.70mm

(Witness plates are 2.67mm thick mild steel)

RESULTS: Acceptor round did not detonate. The witness panel adjacent to the acceptor round had several large perforations and some unburned H.E. deposited on it. There was a tailfin imprint left on the base witness plate by the detonation of the donor round.

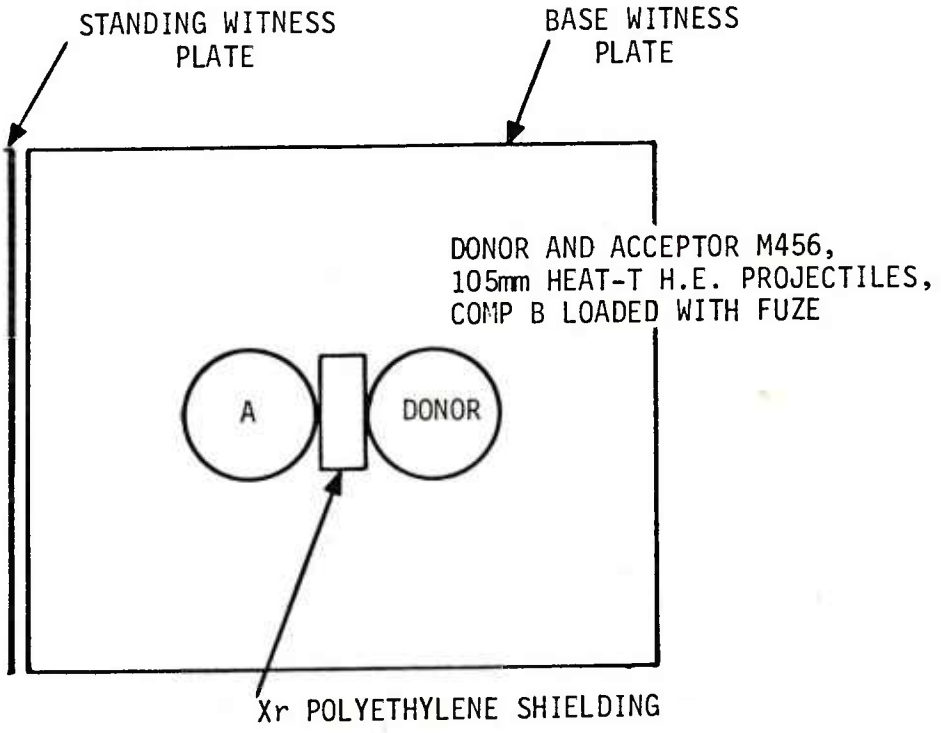
TEST NO: KAA0330D1
DATE: 30 MARCH 1981

DONOR AND ACCEPTOR
PROJECTILES BEFORE TEST

FRAGMENTS OF ACCEPTOR PROJECTILE
RECOVERED AFTER TEST

COMPARTMENTALIZATION SHIELDING TEST

TEST NO: KAA0330E1 DATE: 30 MARCH 1981 TIME: 1630 MST



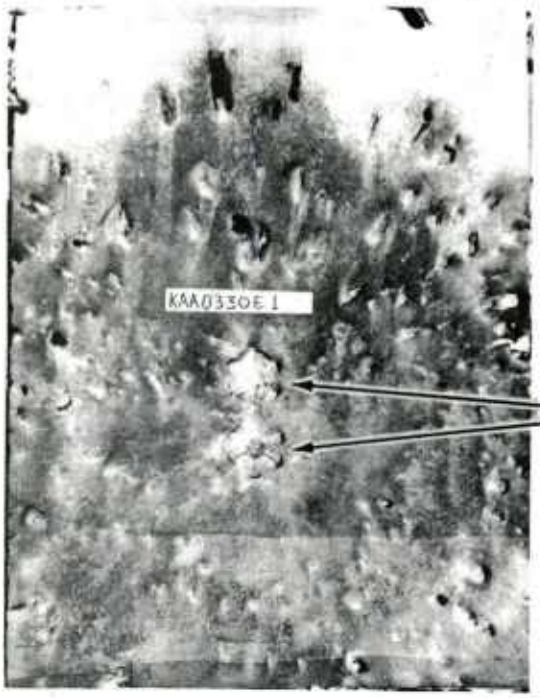
Xr = 9.53mm

(Witness plates are 2.67mm thick mild steel)

RESULTS: Acceptor round detonated. The witness panel had many small perforations in it, but no H.E. was deposited on it. There were two tailfin imprints made in the base witness plate by the detonation of the donor and the acceptor rounds.

TEST NO: KAA0330E1
DATE: 30 MARCH 1981

DONOR AND ACCEPTOR
PROJECTILES BEFORE TEST

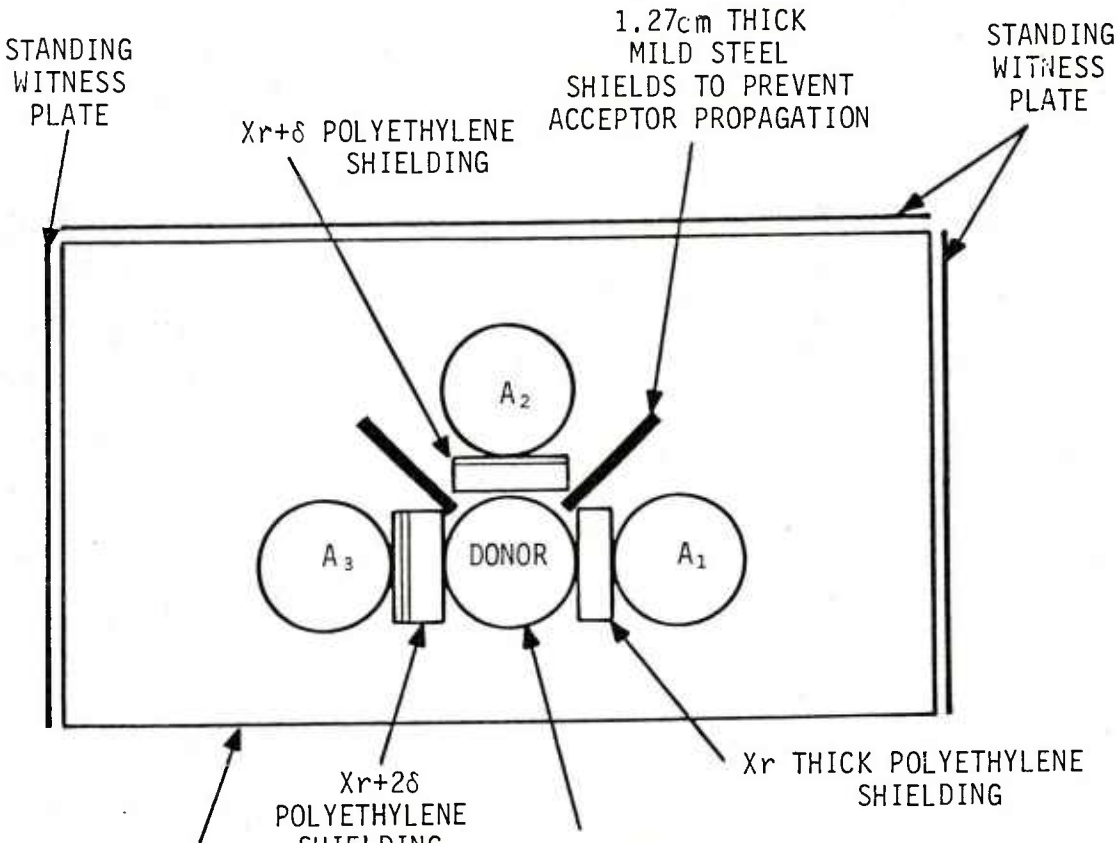


WITNESS PANEL WHICH STOOD
ADJACENT TO ACCEPTOR
PROJECTILE

IMPRINTS MADE ON BASE
WITNESS PLATE BY THE
DETONATIONS OF THE DONOR
AND ACCEPTOR PROJECTILES

COMPARTMENTALIZATION SHIELDING TEST

TEST: KAA0331A1 DATE: 31 MARCH 1981 TIME: 0905 MST



Xr = 12.70mm δ = 3.18mm
Xr+δ = 15.88mm Xr+2δ= 19.05mm

(Witness plates are 2.67mm thick mild steel)

RESULTS: None of the acceptor rounds detonated. The witness panels which were adjacent to the acceptor rounds all had several large perforations. Unburned H.E. was deposited on the witness panels adjacent to A_2 and A_3, but no H.E. remained on the witness panel adjacent to A_1.

TEST NO: KAA0331A1
DATE: 31 MARCH 1981

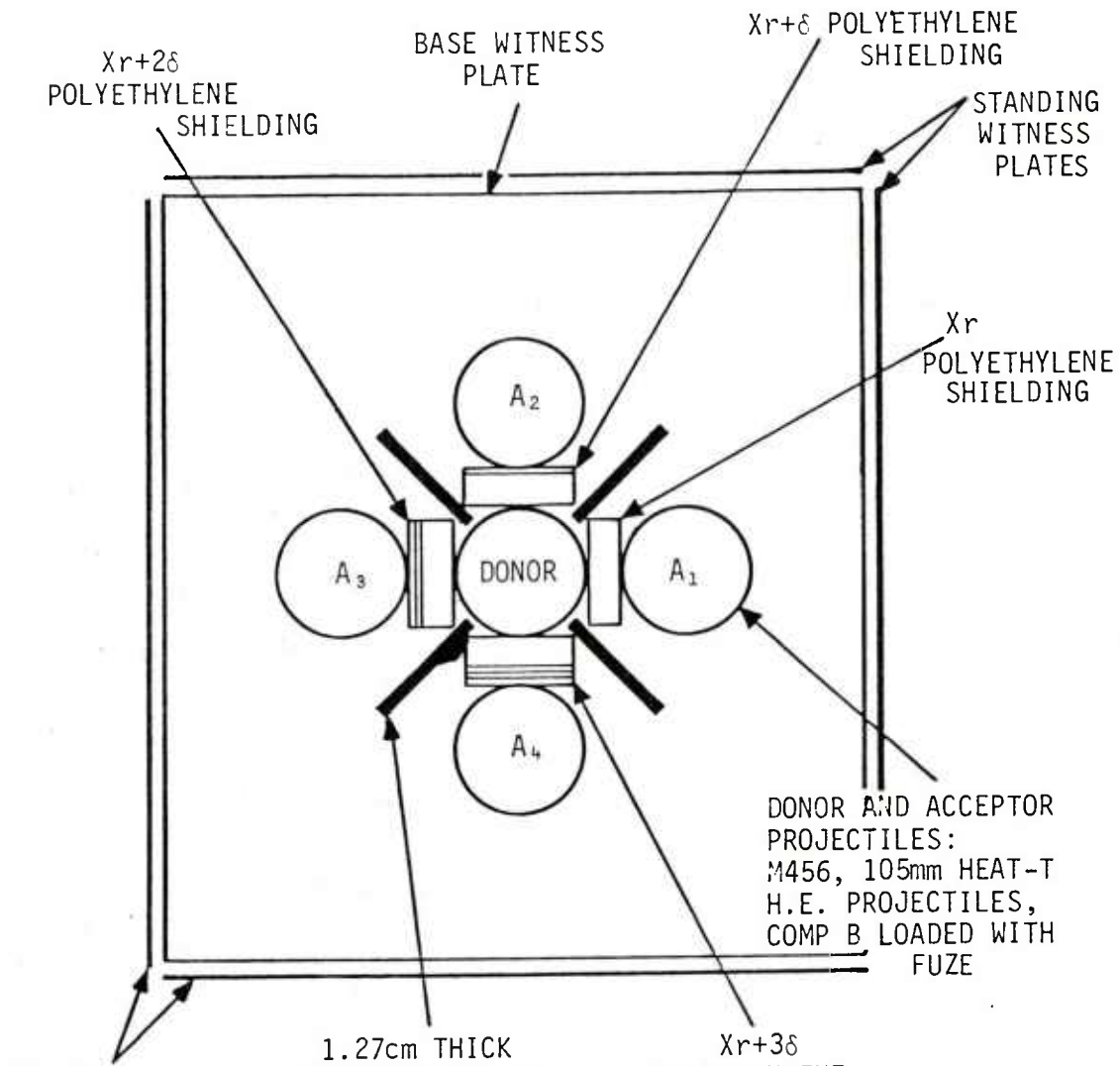
DONOR AND ACCEPTOR
PROJECTILES BEFORE TEST

FRAGMENTS OF ACCEPTOR
PROJECTILES RECOVERED
AFTER TEST

BASE WITNESS PLATE
AFTER TEST

COMPARTMENTALIZATION SHIELDING TEST

TEST: KAA0331B1 DATE: 31 MARCH 1981 TIME: 1000 MST



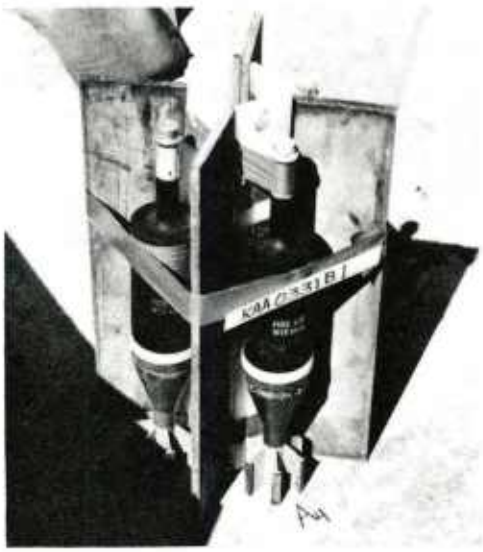
Xr = 9.53mm δ = 3.18mm

Xr+δ = 12.70mm Xr+2δ = 15.88mm Xr+3δ = 19.05mm

(Witness plates are 2.67mm thick mild steel)

RESULTS: Acceptor round A_1 detonated. Fragments from the other acceptor rounds were recovered. The standing witness panel adjacent to A_1 had many small perforations. The witness panel adjacent to A_2 had several large perforations. The witness panels adjacent to A_3 and A_4 had several large perforations and some unburned H.E. deposited on them. The base witness plate had tailfin imprints where A_1 and the donor round had detonated.

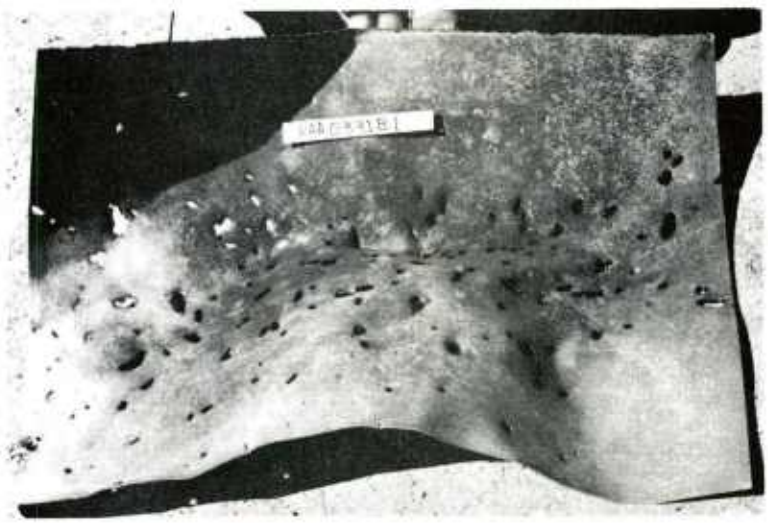
TEST NO: KAA0331B1
DATE: 31 MARCH 1981



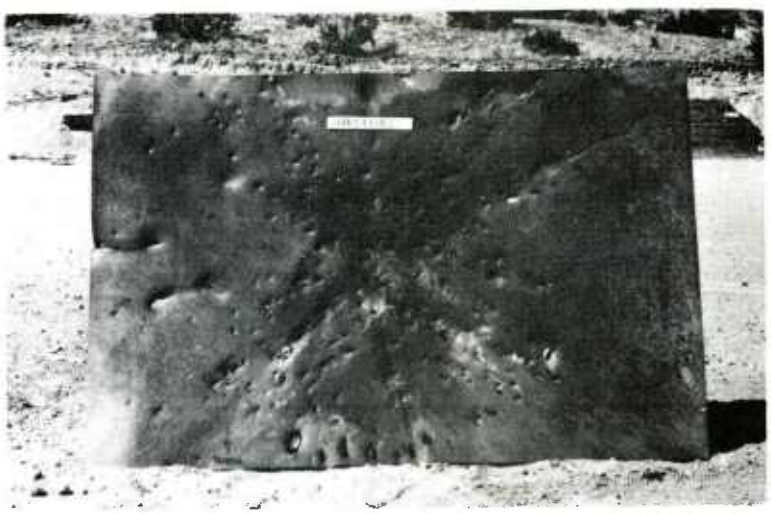
DONOR AND ACCEPTOR
PROJECTILES BEFORE TEST

FRAGMENTS OF ACCEPTOR
PROJECTILES RECOVERED
AFTER TEST

TEST NO: KAA0331B1
DATE: 31 MARCH 1981



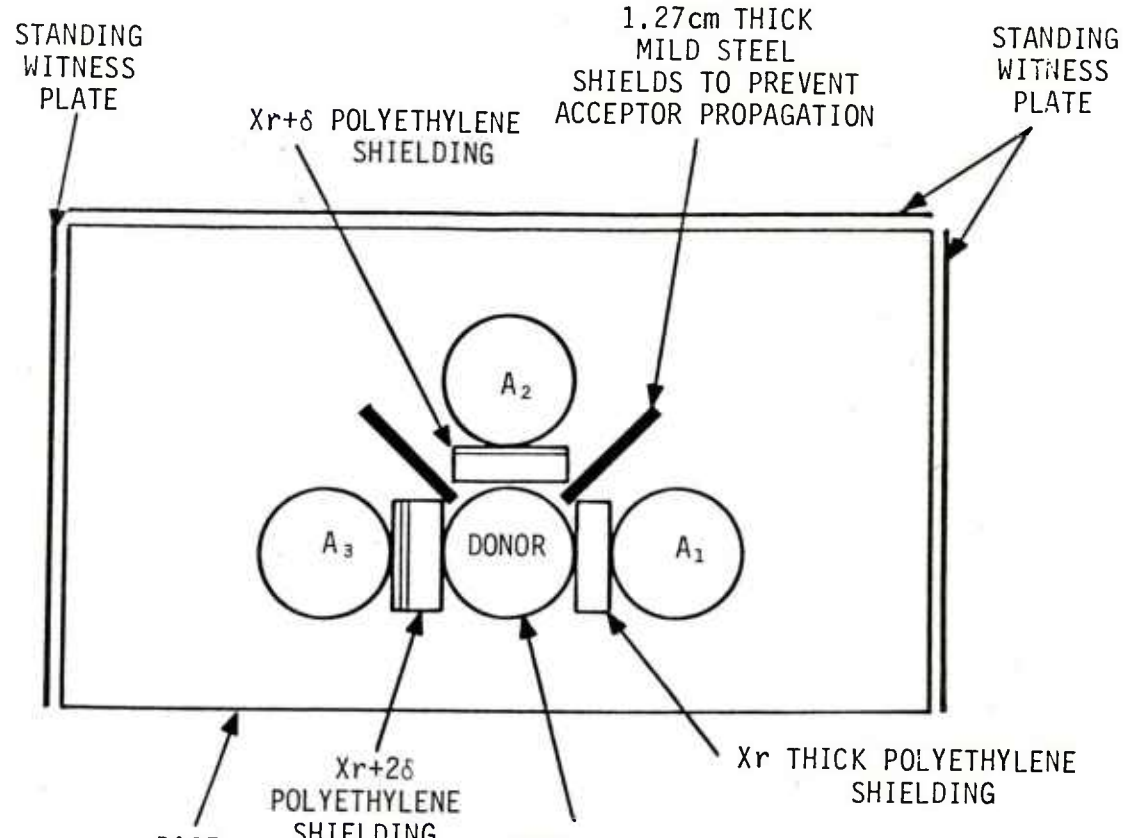
WITNESS PANEL WHICH STOOD
ADJACENT TO ACCEPTOR PROJECTILE, A_1



BASE WITNESS PLATE AFTER TEST

COMPARTMENTALIZATION SHIELDING TEST

TEST: KAA0331C1 DATE: 31 MARCH 1981 TIME: 1110 MST



Xr = 12.70mm δ = 3.18mm
Xr+δ = 15.88mm Xr+2δ= 19.05mm

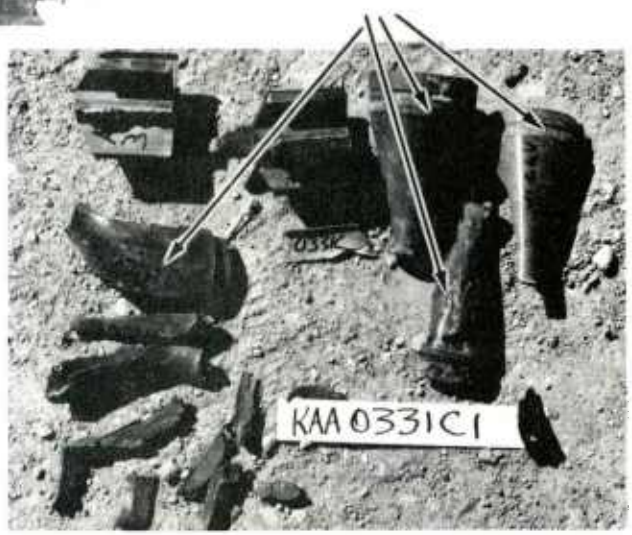
(Witness plates are 2.67mm thick mild steel)

RESULTS: None of the acceptor rounds detonated. The witness panel adjacent to A_1 had no perforations, nor was H.E. deposited on it. The witness panel adjacent to A_2 had two large perforations, and a small amount of unburned H.E. was deposited on it. The witness panel adjacent to A_3 had several large perforations, and some burned and unburned H.E. was deposited on it. A tailfin imprint was left in the base witness plate by the detonation of the donor round.

TEST NO: KAA0331C1
DATE: 31 MARCH 1981

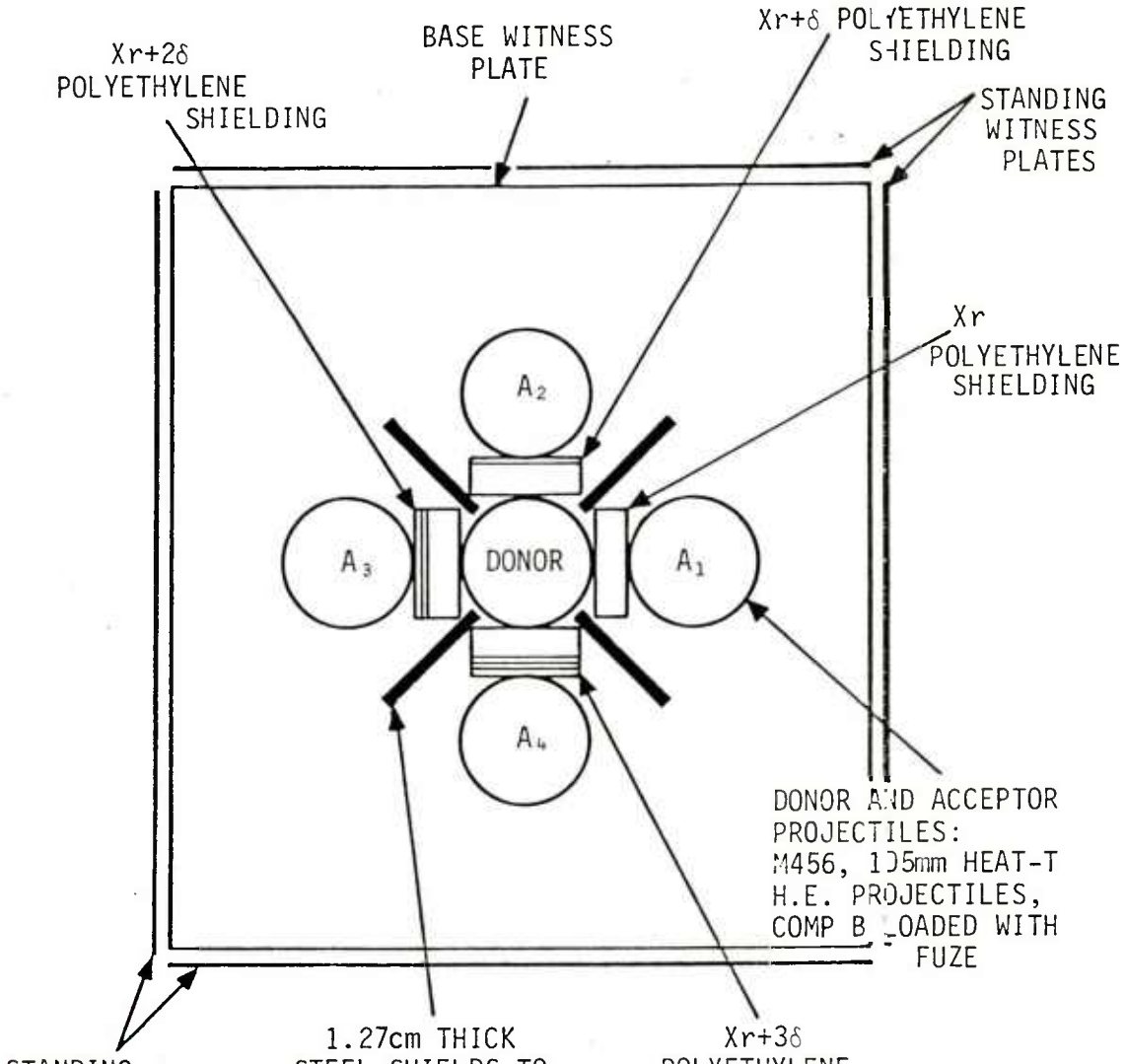
DONOR AND ACCEPTOR
PROJECTILES BEFORE TEST

FRAGMENTS OF ACCEPTOR
PROJECTILES RECOVERED
AFTER TEST



COMPARTMENTALIZATION SHIELDING TEST

TEST: KAA0331D1 DATE: 31 MARCH 1981 TIME: 110 MST



Xr = 9.53mm δ = 3.18mm

Xr+δ = 12.70mm Xr+2δ = 15.88mm Xr+3δ = 19.05mm

(Witness plates are 2.67mm thick mild steel)

RESULTS: Acceptor round A_1 detonated. The witness panel adjacent to A_1 has many small perforations; no H.E. was deposited on it. The witness panels adjacent to A_2 and A_3 had several large perforations, and some burned and unburned explosives were deposited on them. The witness panel adjacent to A_4 had several large perforations, but no H.E. was deposited on it. There were tailfin imprints left by the detonation of A_1 and the donor round.

TEST NO: KAA0331D1
DATE: 31 MARCH 1981

DONOR AND ACCEPTOR
PROJECTILES BEFORE TEST

FRAGMENTS OF ACCEPTOR
PROJECTILES RECOVERED
AFTER TEST

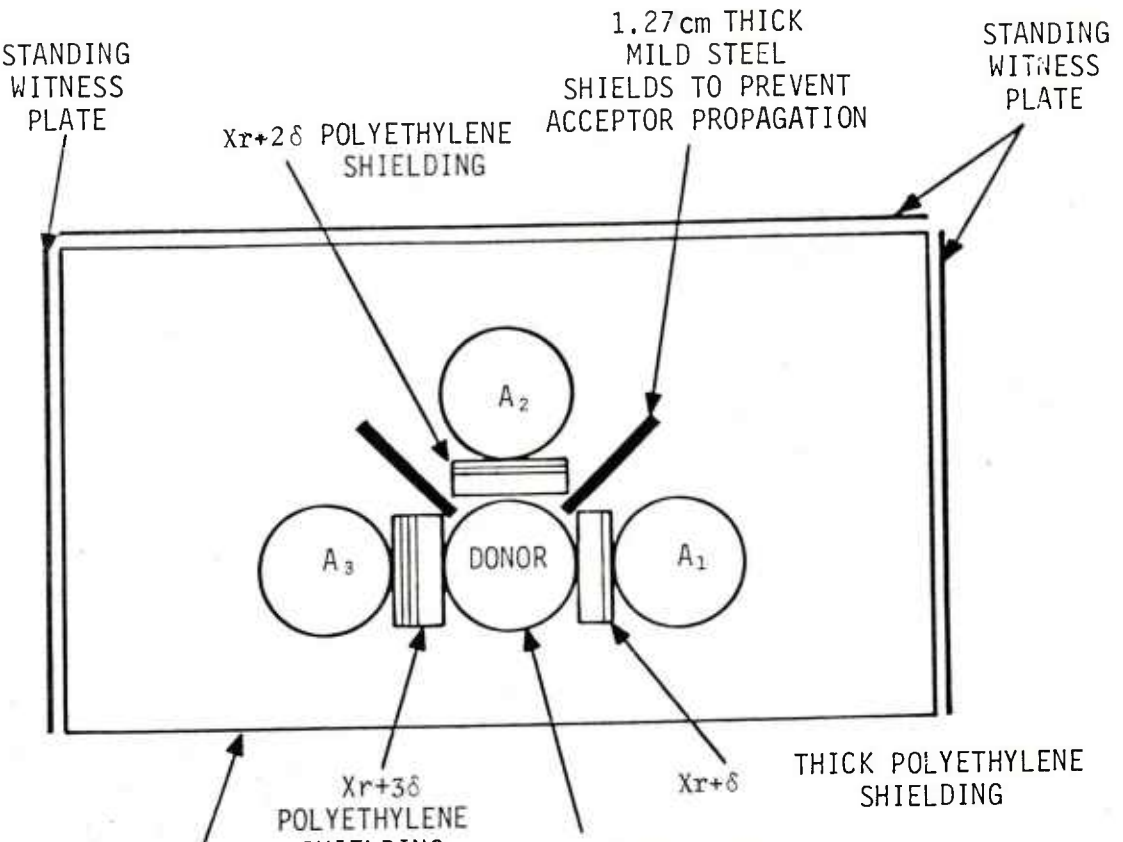
TEST NO: KAA0331D1
DATE: 31 MARCH 1981

STANDING WITNESS PANEL
WHICH STOOD ADJACENT
TO ACCEPTOR A_1

BASE WITNESS
PLATE AFTER
TEST

COMPARTMENTALIZATION SHIELDING TEST

TEST: KAA0331E1 DATE: 31 MARCH 1981 TIME: 1400 MST



Xr = 9.53mm δ = 3.18mm
Xr+2δ = 12.70mm Xr+3δ= 15.88mm

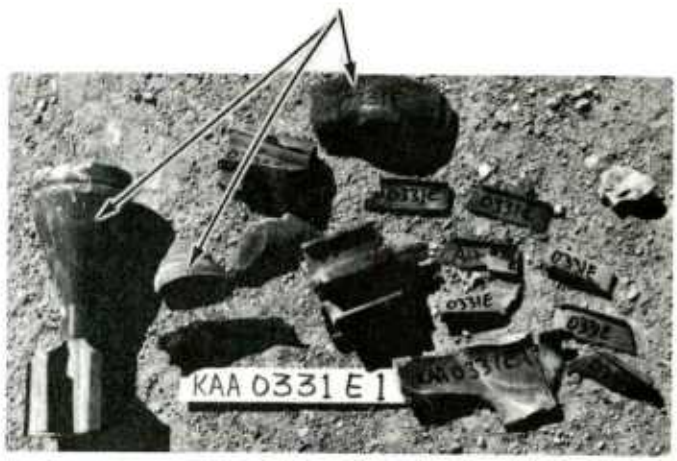
(Witness plates are 2.67mm thick mild steel)

RESULTS: None of the acceptor rounds detonated. The witness panel adjacent to A_1 had a large perforation; some burned and some unburned H.E. was deposited on it. The witness panel adjacent to A_2 had several large perforations, and some burned H.E. was deposited on it. The witness panel adjacent to A_3 was not perforated; there was burned and unburned H.E. deposited on it. The base witness plate had a tailfin imprint from the detonation of the donor round.

TEST NO: KAA0331E1
DATE: 31 MARCH 1981

DONOR AND ACCEPTOR
PROJECTILES BEFORE TEST

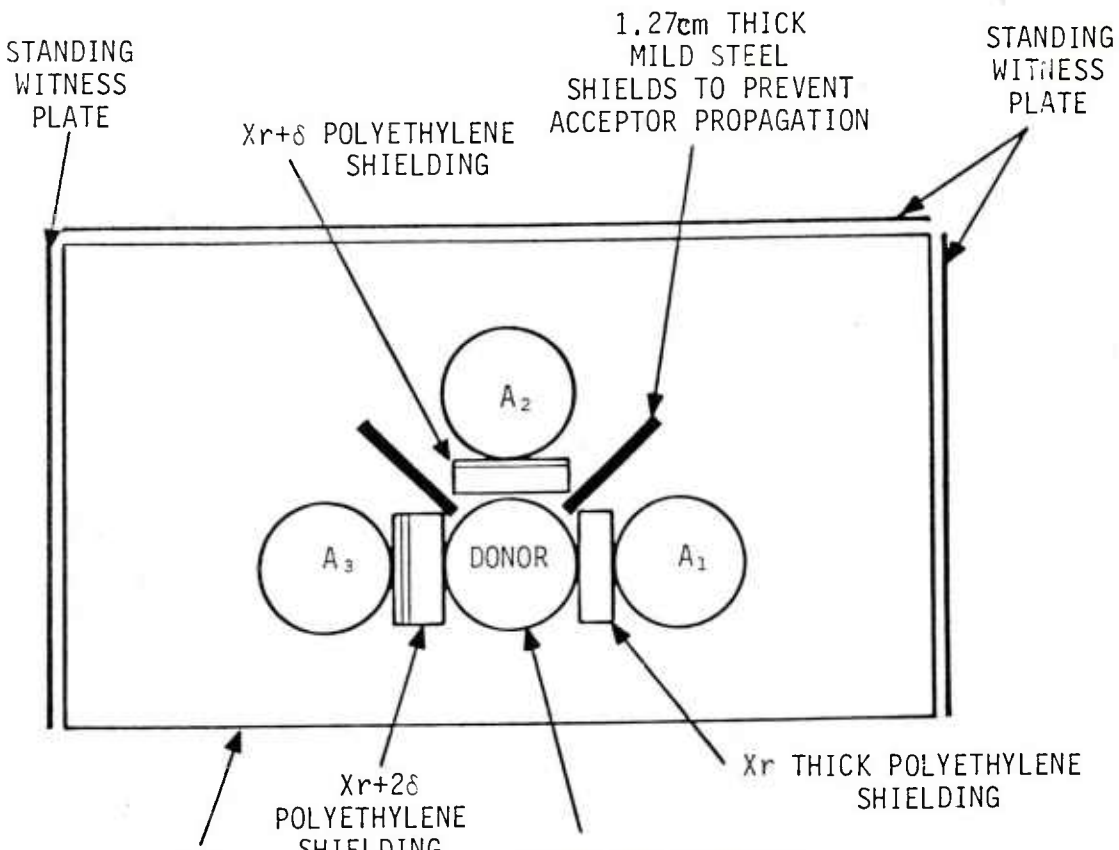
FRAGMENTS OF ACCEPTOR
PROJECTILES RECOVERED
AFTER TEST



BASE WITNESS PLATE
AFTER TEST

COMPARTMENTALIZATION SHIELDING TEST

TEST: KAA0331F1 DATE:31 MARCH 1981 TIME: 1450 MST



Xr = 9.53mm δ = 3.18mm
Xr+δ = 12.70mm Xr+2δ= 15.88mm

(Witness plates are 2.67mm thick mild steel)

RESULTS: None of the acceptor rounds detonated. There were two large perforations in the witness panel adjacent to A_1, but there was no H.E. deposited on it. There were several large perforations in the witness panel adjacent to A_2, and there was some burned and some unburned H.E. deposited on it. A tailfin imprint in the base witness plate was left by the detonation of the donor round.

TEST NO: KAA0331F1
DATE: 31 MARCH 1981

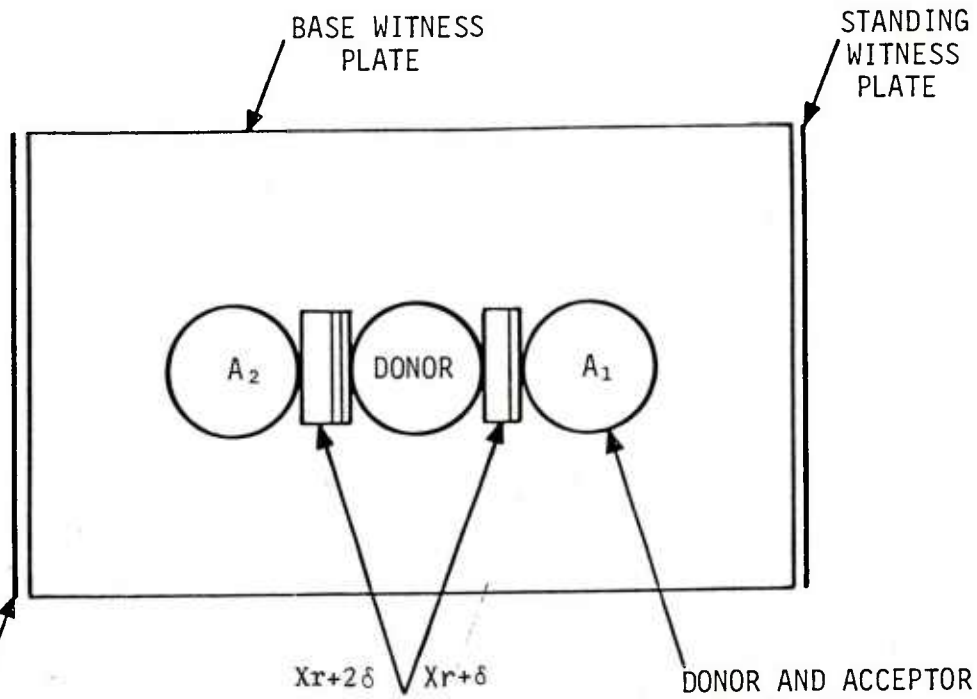
DONOR AND ACCEPTOR
PROJECTILES BEFORE TEST

FRAGMENTS OF ACCEPTOR
PROJECTILES RECOVERED
AFTER TEST

BASE WITNESS
PLATE AFTER
TEST

COMPARTMENTALIZATION SHIELDING TEST

TEST: KAA0331G1 DATE: 31 MARCH 1981 TIME: 1515 MST



Xr = 9.35mm

Xr+δ = 12.70mm δ = 3.18mm

Xr+2δ = 15.88mm

(Witness plates are 2.67mm thick mild steel)

RESULTS: Neither of the acceptor rounds detonated. There were several large perforations in all the witness panels. There was burned H.E. on the witness panel adjacent to A_2. There was a tailfin imprint on the base witness plate from the detonation of the donor round.

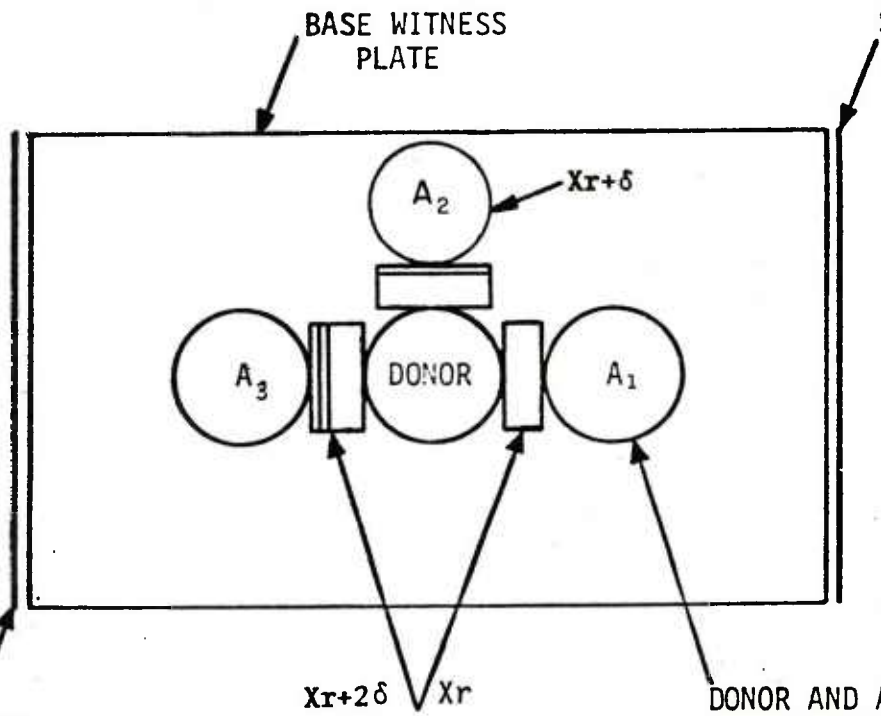
TEST NO: KAA0331G1
DATE: 31 MARCH 1981

DONOR AND ACCEPTOR
PROJECTILES BEFORE TEST

FRAGMENTS OF ACCEPTOR PROJECTILES
RECOVERED AFTER TEST

COMPARTMENTALIZATION SHIELDING TEST

TEST: KAA0331H1 DATE: 31 MARCH 1981 TIME: 1540 MST



Xr = 9.53mm

Xr+δ = 12.70mm δ = 3.18mm

Xr+2δ = 15.88mm

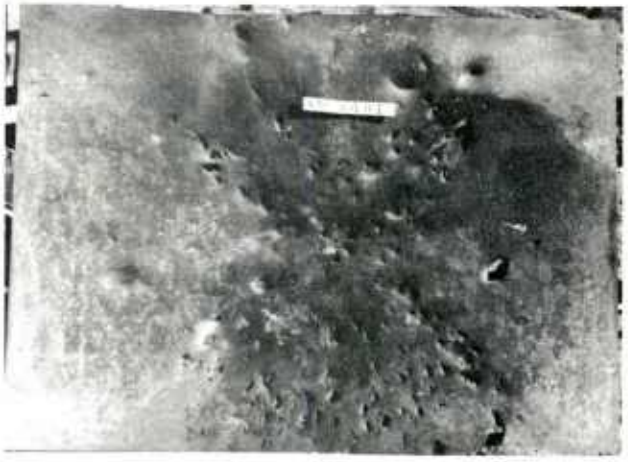
(Witness plates are 2.67mm thick mild steel)

RESULTS: None of the acceptor rounds detonated. The witness panels adjacent to A_1 and A_2 had some burned and some unburned H.E. deposited on them, but there were no perforations. The witness panel adjacent to A_3 had one large perforation and a small amount of burned H.E. On the base witness plate there was a tailfin imprint from the detonation of the donor round.

TEST NO: KAA0331H1
DATE: 31 MARCH 1981

DONOR AND ACCEPTOR
PROJECTILES BEFORE TEST

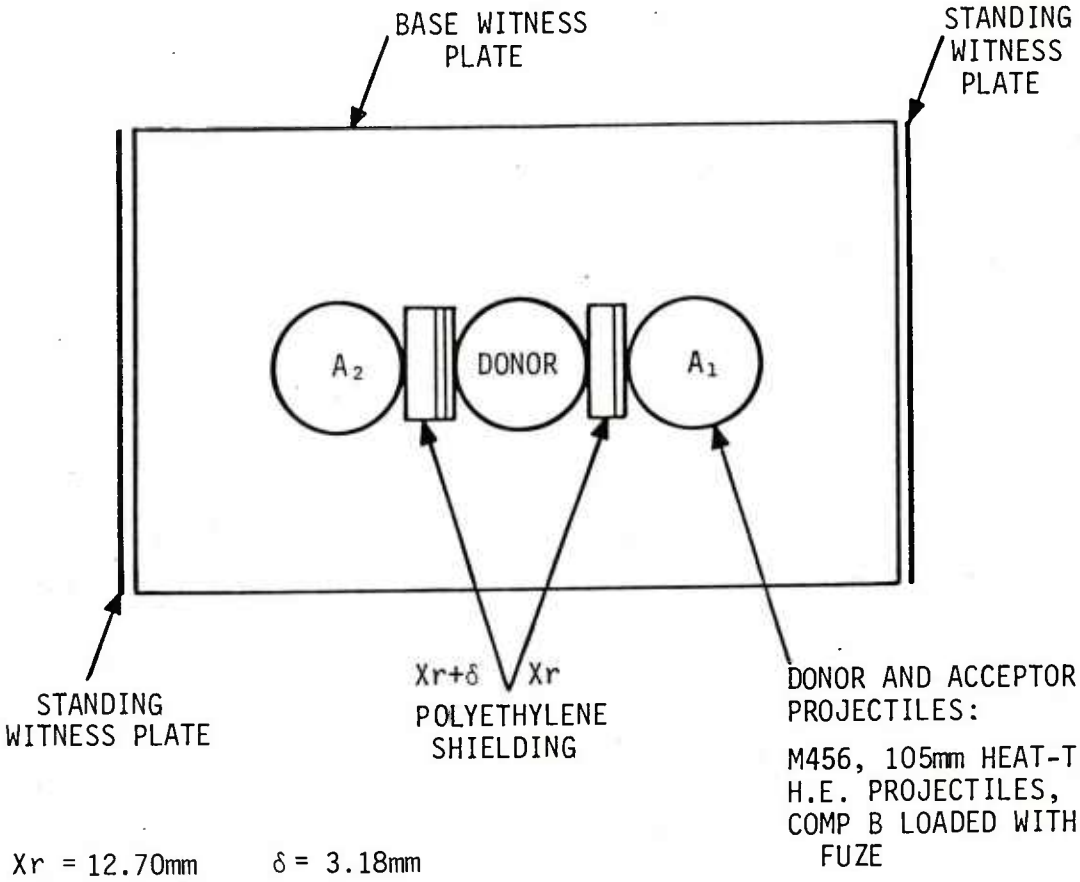
FRAGMENTS OF ACCEPTOR
PROJECTILES RECOVERED
AFTER TEST



BASE WITNESS
PLATE AFTER
TEST

COMPARTMENTALIZATION SHIELDING TEST

TEST: KAA033111 DATE: 31 MARCH 1981 TIME: 1600 MST



Xr = 12.70mm δ = 3.18mm

Xr+δ = 15.88mm

(Witness plates are 2.67mm thick mild steel)

RESULTS: Neither of the acceptor rounds detonated. The witness panel adjacent to A_1 had no perforations and a small amount of unburned explosive deposited on it. The witness panel adjacent to A_2 had two large perforations, and some burned explosive was deposited on it. There was a tailfin imprint on the base witness plate left by the detonation of the donor round only.

TEST NO: KAA0331I1
DATE: 31 MARCH 1981

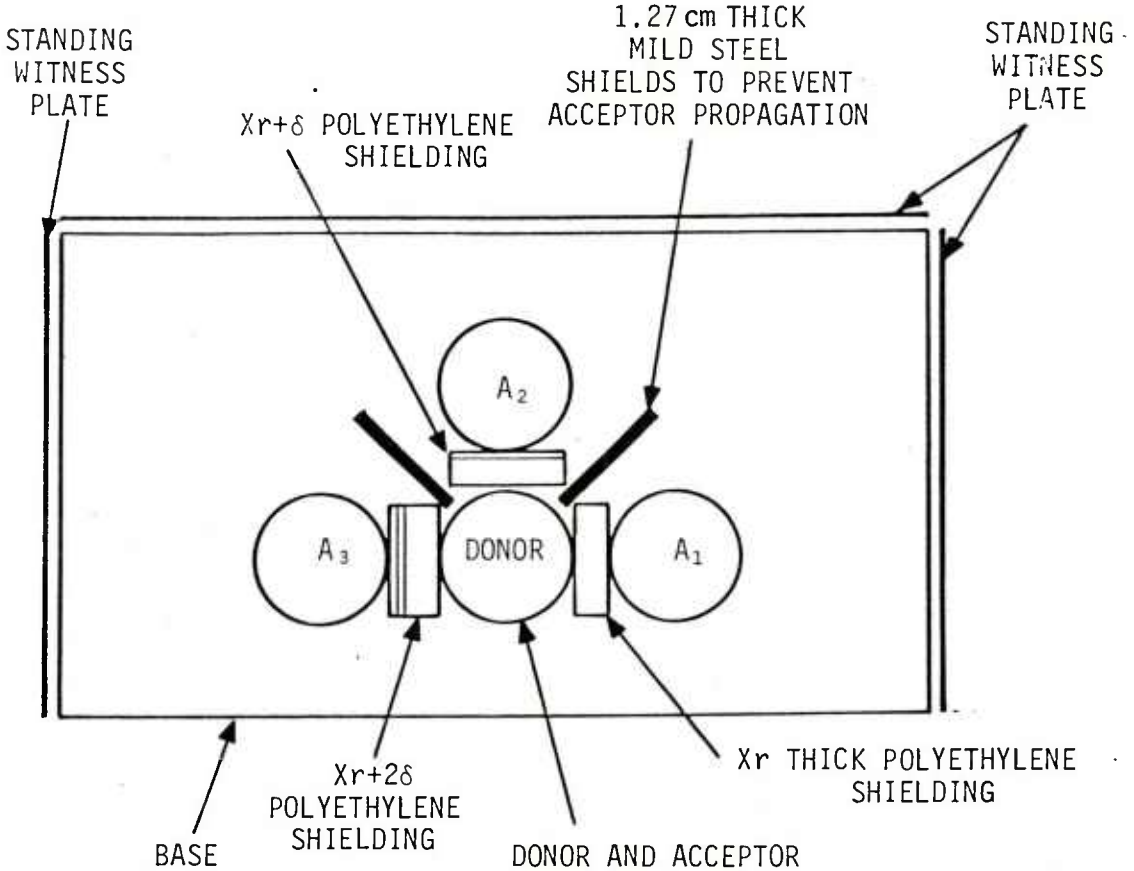
DONOR AND ACCEPTOR
PROJECTILES BEFORE TEST

FRAGMENTS OF ACCEPTOR
PROJECTILES RECOVERED
AFTER TEST

BASE WITNESS PLATE AFTER TEST

COMPARTMENTALIZATION SHIELDING TEST

TEST: KAA0331J1 DATE: 31 MARCH 1981 TIME: 1645 MST



DONOR AND ACCEPTOR PROJECTILES:

M456, 105mm HEAT-T H.E. PROJECTILES, COMP B LOADED WITH FUZE

Xr = 9.53mm δ = 3.18mm
Xr+δ = 12.70mm
Xr+2δ = 15.88mm
(Witness plates are 2.67mm thick mild steel)

RESULTS: Acceptor A_1 detonated. The witness panel adjacent to A_1 had many small perforations; no explosive was deposited on it. The witness panel adjacent to A_2 had one large perforation and some burned explosive was deposited on it. The witness panel adjacent to A_3 had several large perforations, and no explosive was deposited on it. There were tailfin imprints left by the detonation of the donor and acceptor A_1.

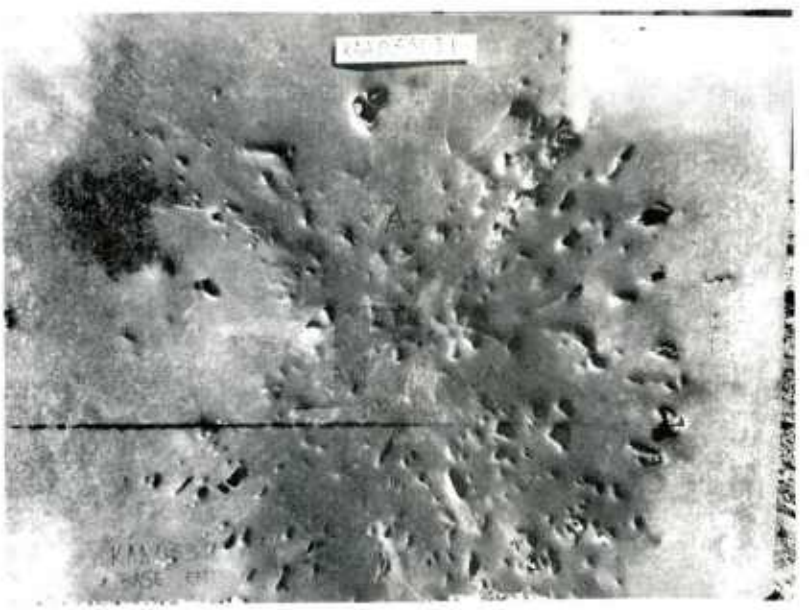
TEST NO: KAA0331J1
DATE: 31 MARCH 1981

DONOR AND ACCEPTOR
PROJECTILES BEFORE TEST

FRAGMENTS FROM ACCEPTOR
PROJECTILES RECOVERED AFTER TEST

TEST NO: KAA0331J1
DATE: 31 MARCH 1981

WITNESS PANEL WHICH STOOD ADJACENT
TO ACCEPTOR PROJECTILE, A_1



BASE WITNESS PLATE AFTER TEST

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